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3D Microstructural and Damage Analysis of Polymer Matrix Composites Using X-ray Computed Tomography with high contrast and submicron voxel resolution

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Conventional optical and electron microscopy requires elaborate sample preparation and physical sectioning / chemical etching to expose sub-surface features. Furthermore, accurate modeling of 3D information from 2D images is difficult. X-ray computed tomography is a rapidly emerging 3-D imaging technique for non-destructive evaluation of biological and non-biological materials [1-5]. Microstructural features of interest at various size scales, in a polymer composite, are fiber and void volume fraction, fiber orientation and architecture, fiber-matrix interface, and various damage modes. These low Z materials coupled with small difference in density between the constituents of the polymer present significant challenges in imaging the various microstructural features within a thin polymer composite lamina layer of a composite laminate, because conventional X-ray detectors of microCT equipment lacks the contrast and resolution. While the contrast may be acceptable for low resolution features (> 5 um) focused in many publications on textiles and textile composites, higher contrast and resolution is required to detect damages, cracks or voids within these materials which are in the order of a few microns to sub-micron lengthscale. While resolution may be improved with submicron x-ray spot sized sources in conventional microCTs (or nanoCTs), most of the resolution improvements are confined to 2D imaging, since higher resolution 3D imaging in the submicron resolution regime places tremendous penalty on sample sizes, thickness and working distance. In this study, a microCT equipment capable of submicron pixel resolution and improved contrast resolution, is used to study the multi-scale microstructure and damage in non-woven and woven continuous fiber and random fiber composites. Resolution of cracks or features as small as 1 to 3 microns in a composite material in relatively large sample of several cm dimension is also possible, making this technique advantageous to study materials AS IS, without much sample trimming or destruction. Some representative images are presented in Figures 1-5. Issues related to non-destructive microstructural and damage analysis of the polymer composites will be highlighted and discussed during presentation.

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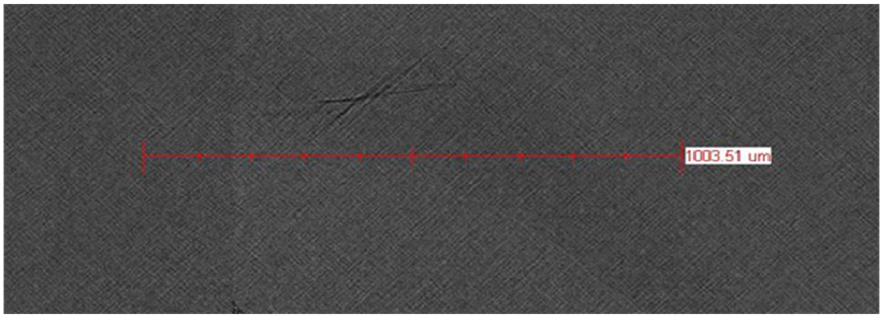

Figure 1. 2-D mosaic image showing damage in [+45,-45] textile laminate

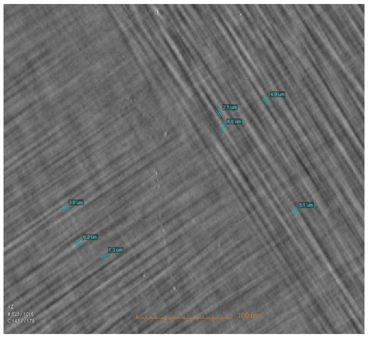

Figure 2. Virtual slice image showing the crimp in a plain weave laminate; individual Carbon fibers and spacing bewteen them are visible

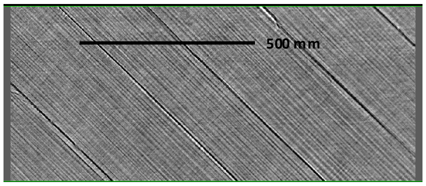

Figure 4 . Virtual slice showing damage in [45] layer of a quasi-isotropic laminate

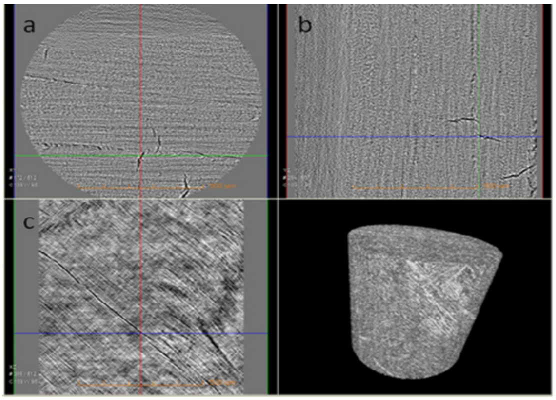

Figure 3. Damage within a yarn of [+45,-45] textile laminate; a,b,c are top edge, side edge and front of the slice of the yarn ; cracking at the crimp is observed in c

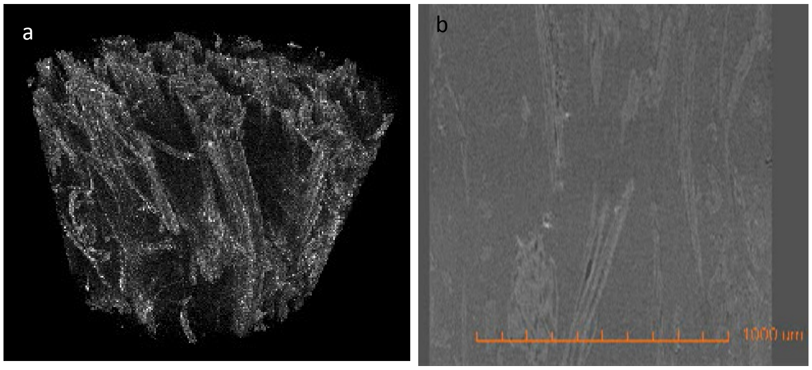

Figure 5. a-reconstructed 3-D image of a hemp fiber mat; b- biopolymer/hemp composite